STABILIZATION OF EXPANSIVE SOIL USING FLY ASH

A dissertation submitted by

Manmay Kumar Mohanty

(710CE1160)

In partial fulfilment of the requirements
For the award of the degree of

Master of Technology (Dual Degree)

In

Civil Engineering

(Geotechnical Engineering)

Department of Civil Engineering

National Institute of Technology, Rourkela

Odisha – 769008, India

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Dedicated to my uncle,
Late Sri. Rajendra Kumar Mohanty,
who will always be in my memories.

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA, ODISHA - 769008

CERTIFICATE

This is to certify that the thesis entitled, "***Stabilization of Expansive Soils Using Fly Ash***" is submitted by **MANMAY KUMAR MOHANTY**, bearing Roll No. **710CE1160** in partial fulfilment of the requirements for the award of Master of Technology (dual degree) in Civil Engineering with specialization in "Geotechnical Engineering", during 2010-2015 session at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Date:

Place: NIT, Rourkela, Odisha

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Without the unconditional support of many people, this thesis wouldn't have seen light of the day.

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ABSTRACT

Nearly 51.8 million hectares of land area in India are covered with Expansive soil (mainly Black Cotton soil). The property of these expansive soils, in general, is that they are very hard when in dry state, but they lose all of their strength when in wet state. In light of this property of expansive soils, these soils pose problems worldwide that serve as challenge to overcome for the Geotechnical engineers. One of the most important aspects for construction purposes is soil stabilization, which is used widely in foundation and road pavement constructions; this is because such a stabilization regime improves engineering properties of the soil, such as volume stability, strength and durability. In this process, removal or replacing of the problematic soil is done; replacement is done by a better quality material, or the soil is treated with an additive. In the present study, using fly ash obtained from Sesa Sterlite, Jharsuguda, Odisha, stabilization of black cotton soil obtained from Nagpur is attempted. With various proportions of this additive i.e. 10%, 20%, 30%, 40% & 50%, expansive soils is stabilized. Owing to the fact that fly ash possess no plastic property, plasticity index (P.I.) of clay-fly ash mixes show a decrease in value with increasing fly ash content. In conclusion, addition of fly ash results in decrease in plasticity of the expansive soil, and increase in workability by changing its grain size and colloidal reaction. Tested under both soaked and un-soaked conditions, the CBR values of clay with fly ash mixes were observed. Analysis of the formerly found result exposes the potential of fly ash as an additive that could be used for improving the engineering properties of expansive soils.

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INTRODUCTION

1.1 Expansive soil

Expansive soils, which are also called as swell-shrink soil, have the tendency to shrink and swell with variation in moisture content. As a result of this variation in the soil, significant distress occurs in the soil, which is subsequently followed by damage to the overlying structures. During periods of greater moisture, like monsoons, these soils imbibe the water, and swell; subsequently, they become soft and their water holding capacity diminishes. As opposed to this, in drier seasons, like summers, these soils lose the moisture held in them due to evaporation, resulting in their becoming harder. Generally found in semi-arid and arid regions of the globe, these type of soils are regarded as potential natural hazard – if not treated, these can cause extensive damage to the structures built upon them, as well causing loss in human life. Soils whose composition includes presence of montmorillonite, in general, display these kind of properties. Tallied in billions of dollars annually worldwide, these soils have caused extensive damage to civil engineering structures.

Also called as Black Cotton soils or Regur soils, expansive soils in the Indian subcontinent are mainly found over the Deccan trap (Deccan lava tract), which includes Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, and some scattered places in Odisha. These soils are also found in the river valley of Narmada, Tapi, Godavari and Krishna. The depth of black cotton soil is very large in the upper parts of Godavari and Krishna, and the north-western part of Deccan Plateau. Basically, after the chemical decomposition of rocks such as basalt by various decomposing agents, these are the residual soils left behind at the place of such an event. Cooling of volcanic eruption (lava) and weathering another kind of rock – igneous rocks – are also processes of formation of these type of soils. Rich in lime, alumina, magnesia, and iron, these soils lack in nitrogen, phosphorus and organic content.

Consisting of high percentage of clay sized particles, the colour of this soil varies from black to chestnut brown. 20% of the total land area, on an average, of this country is roofed by expansive soils. These soils are suitable for dry farming and for the growth of crops like cotton, rice, jowar, wheat, cereal, tobacco, sugarcane, oilseeds, citrus fruits and vegetables; the reason behind it is owed to the moisture retentive capacity of expansive soils, which is high.

In the semi-arid regions, just in the last couple of decades, damages due to the swelling-shrinking action of expansive soils have been observed prominently in form of cracking and break-up of roadways, channel and reservoir linings, pavements, building foundations, water lines, irrigation systems, sewer lines, and slab-on-grade members.

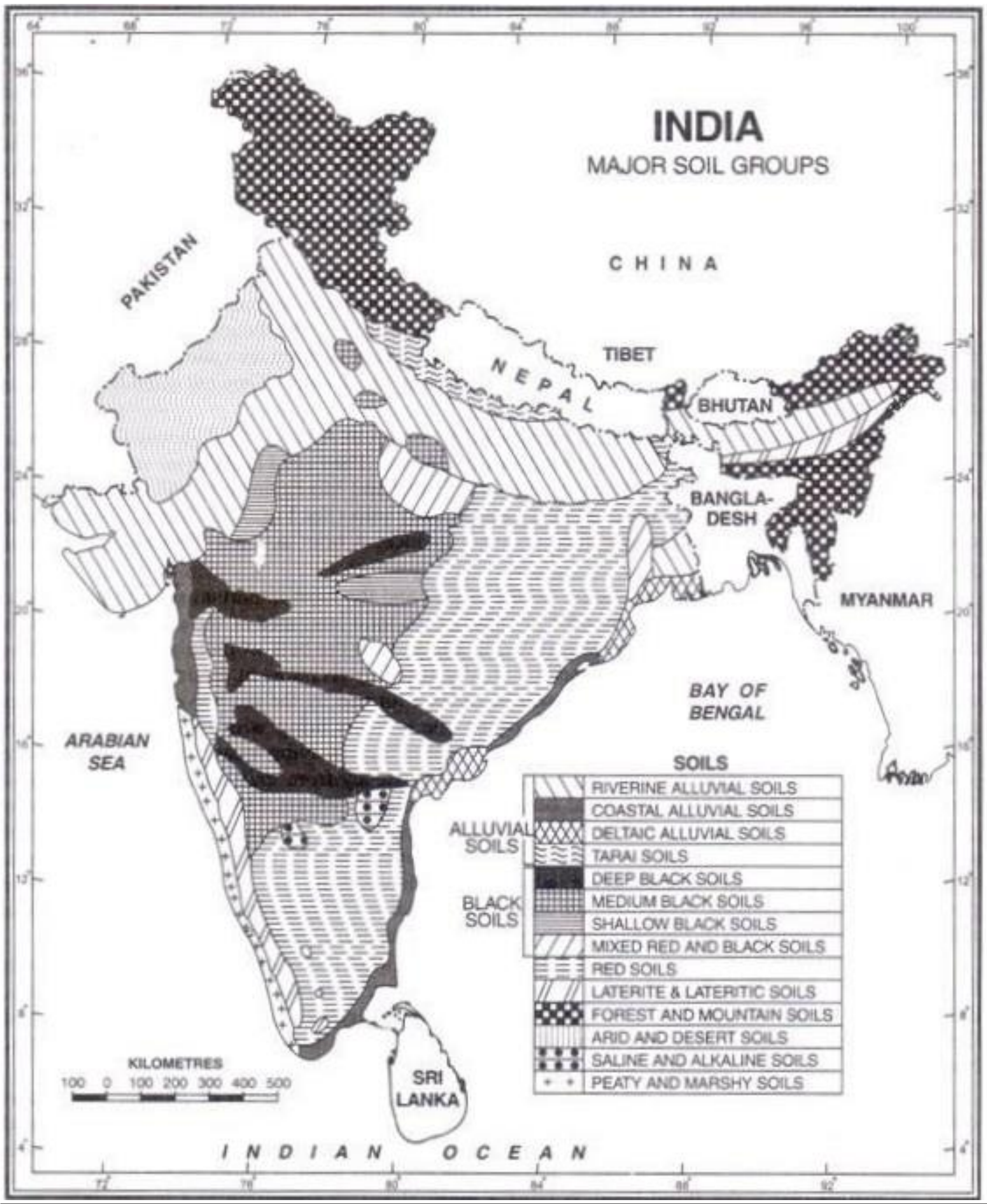

Figure 1 **Major Soil Types in India**

1.2 Fly Ash

A waste material extracted from the gases emanating from coal fired furnaces, generally of a thermal power plant, is called fly ash. One of the chief usages of volcanic ashes in the ancient ages were the use of it as hydraulic cements, and fly ash bears close resemblance to these volcanic ashes. These ashes were believed to be one of the best pozzolans (binding agent) used in and around the globe.

The demand of power supply has exponentially heightened these days due to increasing urbanization and industrialization phenomena. Subsequently, this growth has resulted in the increase in number of power supplying thermal power plants that use coal as a burning fuel to produce electricity. The mineral residue that is left behind after the burning of coal is the fly ash. The Electro Static Precipitator (ESP) of the power plants collect these fly ashes.

Production of fly ash comes with two major concerns – safe disposal and management of fly ash. Because of the possession of complex characteristics of wasters which are generated from the industries, and their hazardous nature, these wastes pose a necessity of being disposed in a safe and effective way, so as to not disturb the ecological system, and not causing any sort of catastrophe to human life and nature. Environmental pollution is imminent unless these industrial wastes are pre-treated before their disposal or storage.

Essentially consisting of alumina, silica and iron, fly ashes are micro-sized particles. Fly ash particles are generally spherical in size, and this property makes it easy for them to blend and flow, to make a suitable concoction. Both amorphous and crystalline nature of minerals are the content of fly ash generated. Its content varies with the change in nature of the coal used for the burning process, but it basically is a non-plastic silt. For waste liners, fly ash is a potential material that can be employed; and in combination with certain minerals (lime and bentonite), fly ash can be used as a barrier material. In present scenario, the generation of this waste material in picture (fly ash) is far more than its current utilization. In other words, we are producing more of fly ash than we can spend.

1.2.1 Generation and Disposal

Usage of coal in thermal power plants for the generation of steam is a common practice. A method that was proved to be non-energy efficient was used in the past, where coal in form of lumps were expended in the furnaces of the boilers to generate the evaporated content: steam. Thus, in order to optimize the production of energy from coal mass, the thermal power plants began to use pulverized coal mass instead of the aforementioned content. In this process, firstly, this pulverized coal is infused into the combustion chamber, where the instant but efficient burning of fuel happens. The ash formed as a result of this is called the fly ash, and this fly ash contains molten minerals. The steam around this molten mass, when the coal ash travels with the flue gases, results in the spherical shape of the fly ash particle. Next, the employment of the economizer recovers the heat from the steam gases and fly ash. As a result of this process, the temperature of the fly ash shows a sudden reduction in value. If this temperature fall is rapid, then the resulting structure of the fly ash material is amorphous. However, if the temperature drop during this cooling process is gradual, then the fly ash assumes a more crystalline in nature. This shows the implementation of the economizer, and how it improves the reactivity process.

In the process where fly ash is not subjected to the economizer, it forms a 4.3% soluble matter, and its pozzolanic activity index clocks to 94%. Whereas, during the process where the fly ash exposed to the economizer, its pozzolanic activity clocks to 103% and it forms a 8.8% soluble matter. In conclusion, fly ashes are separated from the flue gases by a mechanical dust collector, which is commonly referred to as Electro Static Precipitator (ESP), or scrubbers. Free of fly ashes, the rest of the flue gases are liberated into the atmosphere via the chimney.

With about 90%-98%, the efficiency of ESPs for the separation of finer and lighter fly ash particles is high. In general, the fly ash consists of four to six hoppers, named as field. The fineness of the fly ash particles collected are thus proportional to the number of fields available in an ESP. Therefore, the fly ashes that are collected from the first hopper have a specific surface area of about 2800 cm^2/gm, whereas the fly ash collected from the last hopper exhibit a greater specific surface area, that is, 8200 cm^2/gm. With the scorching of pulverized coal, the resulting ash content forming during the process are either collected as fly ash or bottom ash. 80% of coal ashes that are removed from the flue gases are recovered as fly ash, whereas the remaining 20%, that are generally coarser in size, are collected at the bottom of the furnace as bottom ash. Either in dry form, or its collection from a water-filled hopper, bottom ash is taken from the bottom of the furnace. When there is a sufficient amount of bottom ash in the water-filled hopper, beyond which its disposal becomes imminent before moving on to the next process, the transference can occur by water jets or water sluice to a disposal pond which. This disposed waste is then called as pond ash. The below figure gives an idea of disposal of coal ash in a thermal power plant where coal is a fuel.

1.2.2 Classification of fly ash

The extracted ash from the flue gases via an Electro Static Precipitator, after the process of pulverization, is called fly ash. It is the finest of particles among bottom ash, pond ash and fly ash. With some unburned carbon, the fly ash chiefly consists of non-combustible particulate matter. These generally consists of silt-sized particles. On the basis of a lime reactivity test, fly ashes have been classified into four different types, as given:

- Cementitious fly ash
- Cementitious and pozzolanic fly ash
- Pozzolanic fly ash
- Non-pozzolanic fly ash

With free lime content and negligible reactive silica, this fly ash is called as cementitious. As opposed to this, with negligible free lime content, and chiefly reactive silica, this fly ash is called pozzolanic fly ash. Both reactive silica and free lime are predominant in cementitious and pozzolanic fly ash. Neither free lime, nor reactive silica are present in non-pozzolanic fly ash. The distinguishable difference between cementitious fly ash and pozzolanic fly ash is that the cementitious fly ash hardens when it comes in connexion with water, whereas the pozzolanic fly ash hardens only after the activated lime reacts with water. Cementitious & Pozzolanic Fly Ash and Pozzolanic Fly Ash are the types that are found widely.

Based on the chemical composition of fly ash, fly ash has been categorized into two categories, as given:

- Class C fly ash
- Class F fly ash

Burning of sub-bituminous type of coal and lignite, which contains more than 20% Calcium Oxide, gives the Class C fly ash. By ignition of anthracite and bituminous type of coal, Class F fly ash comes into the picture. This fly ash contains less than 20% Calcium Oxide.

The chemical configuration of Class C and Class F fly ashes are as follows, in the given table:

Table 1 **Chemical requirement of class C and class F fly ashes (data source: ASTM C618-94a)**

Particulars		**Fly ash**	
		Class F	**Class C**
$SiO_2 + Al_2O_3 + Fe_2O_3$	**% minimum**	70.0	50.0
SO_2	**% maximum**	5.0	5.0
MC	**% maximum**	3.0	3.0
LOI	**% maximum**	6.0	6.0

1.2.3 Utilization of Fly Ash

The utilization of fly ash can be largely grouped into following three classes:

- The Low Value Utilizations, which includes back filling, structural fills, road construction, soil stabilization, embankment & dam construction, ash dykes, etc.
- The Medium Value Utilizations, which includes grouting, cellular cement, pozzolana cement, bricks/blocks, soil amendment agents, prefabricated building blocks, fly ash concrete, weight aggregate, etc.
- The High Value Utilizations, which includes, fly ash paints, ceramic industry, extraction of magnetite, distempers, metal recovery, acid refractory bricks, floor and wall tiles, etc.

After these, there is still a large wastage of fly ash material observed; however, this has led to evolution of large number of technologies for the management of fly ashes. Thanks to this, the utilization of fly ash has increased to 73 MT by the year 2012. Years 2010-2012 saw a wide acceptance of fly ash as a product that can be used in various purposes. Presently, the production of fly ashes in India is about 130 MT/year, and this is expected to rise by 400 MT by the year 2016-2017, as stated by 2^{nd} annual international summit for fly ash utilization 2012, scheduled on 17^{th}-18^{th} of January, 2013 at NDCC II convention centre, NDMC Complex, New Delhi, India.

Table 2 **Production & Utilization of fly ashes in different countries**
Ref: Alam and Akhtar, International Journal of emerging trends in engineering and development, Vol.1 [2] (2011)

Country	Annual Ash Production (MT)	Ash Utilization in %
India	131	56
China	100	45
Germany	40	85
Australia	10	85
France	3	85
Italy	2	100
USA	75	65
UK	15	50
Canada	6	75
Denmark	2	100
Netherland	2	100

As a palpable conclusion from the previous table, the fly ash utilization in India is about 56%, as in 2010-2012, which leads to the fact that the rest 44% are waste material, dumped/disposed chiefly out in the open, and considering the adverse effect of this waste material on our environment, it is of necessity to utilize all of the fly ash produced by coal based thermal power plants. An increase of efforts have to be observed if we were to achieve a 100% utilization of this waste product. If we were to execute the usage of fly ash properly in low value applications, more than 60% utilization of fly ash we currently produce can be seen. In present scenario, India is 65%-70% dependent on production of energy by coal based thermal power plants, which tallies the fly ash production of the country, as stated earlier, up to 130 MT/year.

Table 3 **Utilization of fly ash for different purposes. Data source: Ministry of Environment & Forests**

Mode of Fly ash applications	% Utilization
Dykes	35
Cement	30
Land development	15
Building	15
Others	5

1.3 Reaction mechanism of Fly ash and expansive soil

By itself, fly ash has little cementitious value, however, this changes in presence of moisture, with which it reacts chemically, and forms cementitious compounds. These compounds attributes to the improvement of compressibility and strength characteristics of a soil. Both classes of Fly ash (C & F) are pozzolans i.e. they contain siliceous and aluminous materials. Fly ash can thus produce an assortment of divalent and trivalent cations ($Ca^{2+}, Fe^{3+}, Al^{3+}$ etc.) under conditions that are ionized in nature, which in return can encourage flocculation of dispersed clay particles. Expansive soils can thus be theoretically stabilized in an effective manner by cationic exchange with fly ash.

1.4 Justification of research

Almost 20% of land in India is roofed by expansive soils. With the rapid growth in industrialization and urbanization, land scarcity appears to be an imminent threat.

Construction of civil engineering structures on expansive soils, however, pose a major risk to the structure in itself, because of the greater degree of instability in these kinds of soil. Tallied in billions of dollars per year is the loss in property every year globally owing to the instability in the expansive soils. On the other hand, disposal of fly ash has become a growing issue. India, as a developing country, is highly dependent on coal based thermal power plants for production energy, and this dependency isn't going to falter anytime soon. Pulverization of coal in these power plants produces many waste materials, including fly ash. As of 2012, the generation of fly ash rose to 130 MT/year. However, only 56% of this generated fly ash waste were only utilized. The residual fly ash is disposed off in places, and this poses threat to health, and also the reduction in land area that can be otherwise utilized for purposes other than the disposal of fly ash.

Keeping both the issues in mind, this research of stabilizing expansive soil using fly ash is justified.

1.5 Objective of Research

- To check the ambit of reducing expansiveness and improving bearing capacity value by adding additives.
- Also to establish the usage of Fly Ash as an additive, thereby helping utilize it which otherwise always lays as fine waste product from thermal power plants.

Chapter 2

LITERATURE REVIEW

2.1 Origin and occurrence of expansive soil

Clay mineral is the key element which divulges the swelling characteristics to any ordinary non-swelling/non-shrinking soil. Montmorillonite, out of several types of clay minerals has the maximum amount of swelling potential. In-situ formation of chief clay minerals occurs under alkaline conditions, or sub-aqueous decomposition of blast rocks can be seen the origin of such soil – expansive soil. These type of soil can also be formed due to weathering under alkaline environments, and under adequate supply of magnesium or ferric or ferrous oxides. Given there’s a good availability of alumina and silica, the formation of Montmorillonite is favoured.

2.2 Nature of expansive soil

Swelling in clays can be sub-categorized into two distinctive types, namely:

- ❖ Elastic rebound in the compressed soil mass due to reduction in compressive force.
- ❖ Imbibing of water resulting in expansion of water-sensitive clays.

Swelling clays are the clays that exhibit latter type of swelling, where the clay minerals with largely inflating lattice are present. One of the fundamental characteristics of clayey soil is that they display little cohesion and strength when wet, but they become hard when devoid of water. However, all of them do not swell due to wetting action. Decrease in ultimate bearing capacity at saturation, and large differential settlement due to this occurs. Thus, clayey soils exhibit foundation problems.

2.3 Clay Mineralogy

On the basis of their crystalline arrangement, clay minerals can be categorized into three general groups, namely:

- Kaolinite group
- Montmorillonite group
- Illite group

2.3.1 Kaolinite group

A clay mineral which has a chemical composition $Al_2Si_20_5(OH)_4$ is called Kaolinite. This type of clay mineral has a layered silicate, with linkage to one octahedral sheet of alumina through oxygen atoms. China clay or Kaolin is the name given to rocks that are rich in this mineral. A thickness of 7Å is exhibited by the stacked layers of kaolinite; as a result of this, kaolin group of minerals are seen to be the most stable, which is also because of the fact that water cannot enter between the sheets to inflate that unit cell.

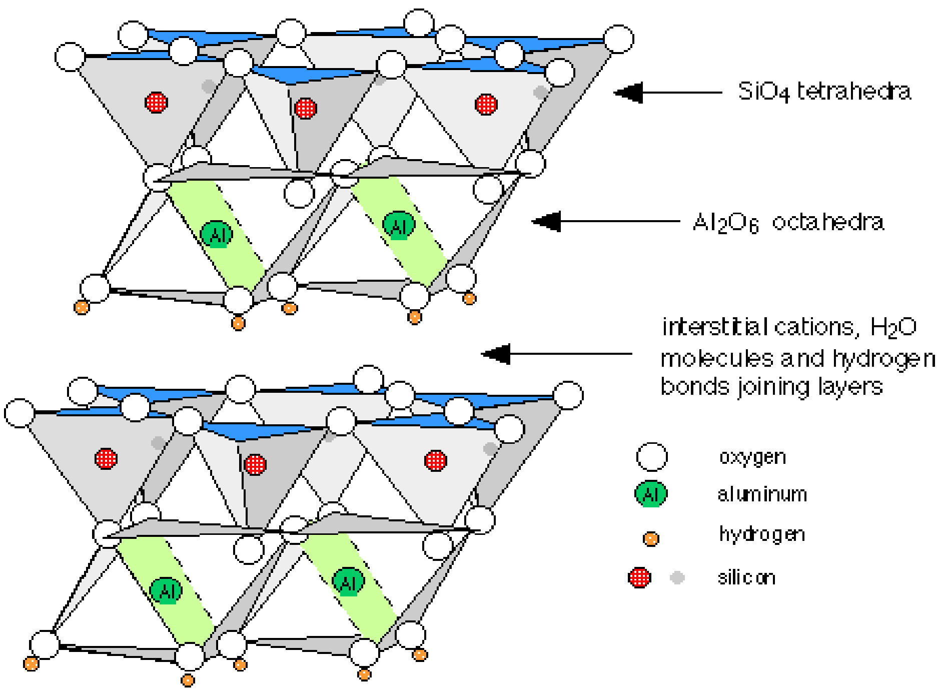

Figure 2 **Atomic structure of kaolinite**

2.3.2 Montmorillonite group

Two silica tetrahedral sheets combined with a central alumina octahedral sheet comprise the structural arrangement of Montmorillonite. The bond between crystal links is weak here. Thus, the soil containing higher percentage of Montmorillonite minerals demonstrate high shrinkage and swelling characteristics, depending on the nature of exchangeable cation present. The common layer of a Montmorillonite unit is formed by one of the hydroxyl layers of the octahedral sheet and the tips of the tetrahedrons from each silica sheet. Atoms which are common to both silica and gibbsite layers never participate in the process of swelling. During weak bond between the crystal forms, water can penetrate, breaking the structures to 10Å structural units.

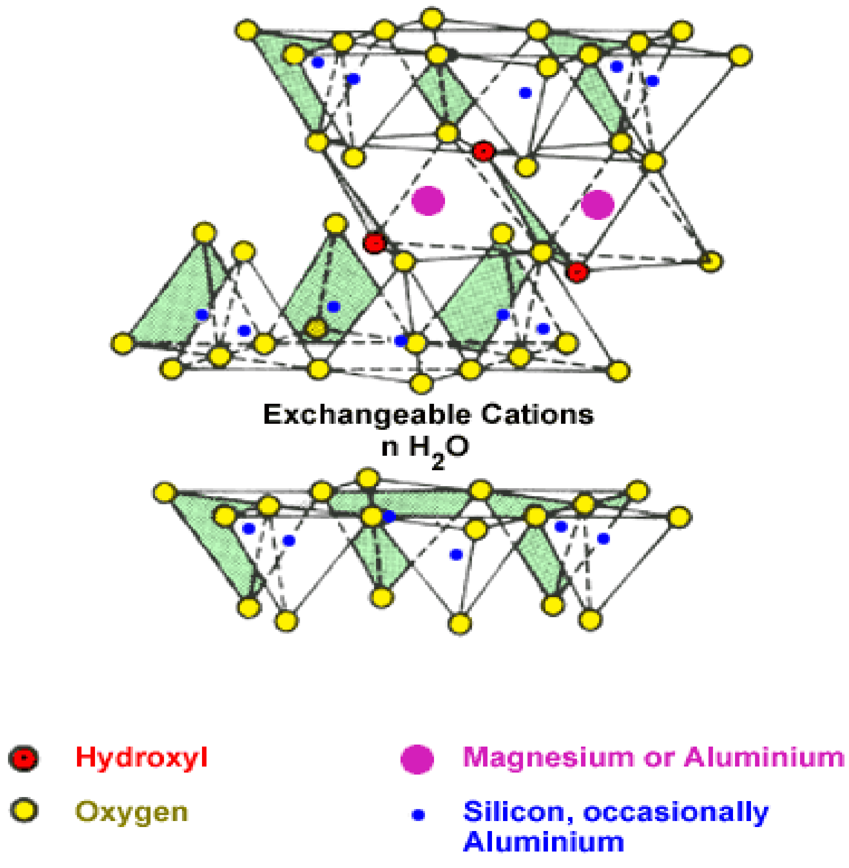

Figure 3 **Atomic structure of montmorillonite**

2.3.3 Illite group

As far as structural arrangement is concerned, Illite minerals fall between Montmorillonite and Kaolinite group. As in case of Montmorillonite unit structure, two silica tetrahedral sheets combined with a central alumina octahedral sheet comprise the structural arrangement of Illite. The spacing between the elementary silica-gibbsite-silica sheets depend largely upon the availability of water to occupy the space. Owing to this reason, Montmorillonite is believed to have an expanding lattice. However, in presence of excess water, Illite can split up into individual layers of 10Å thick.

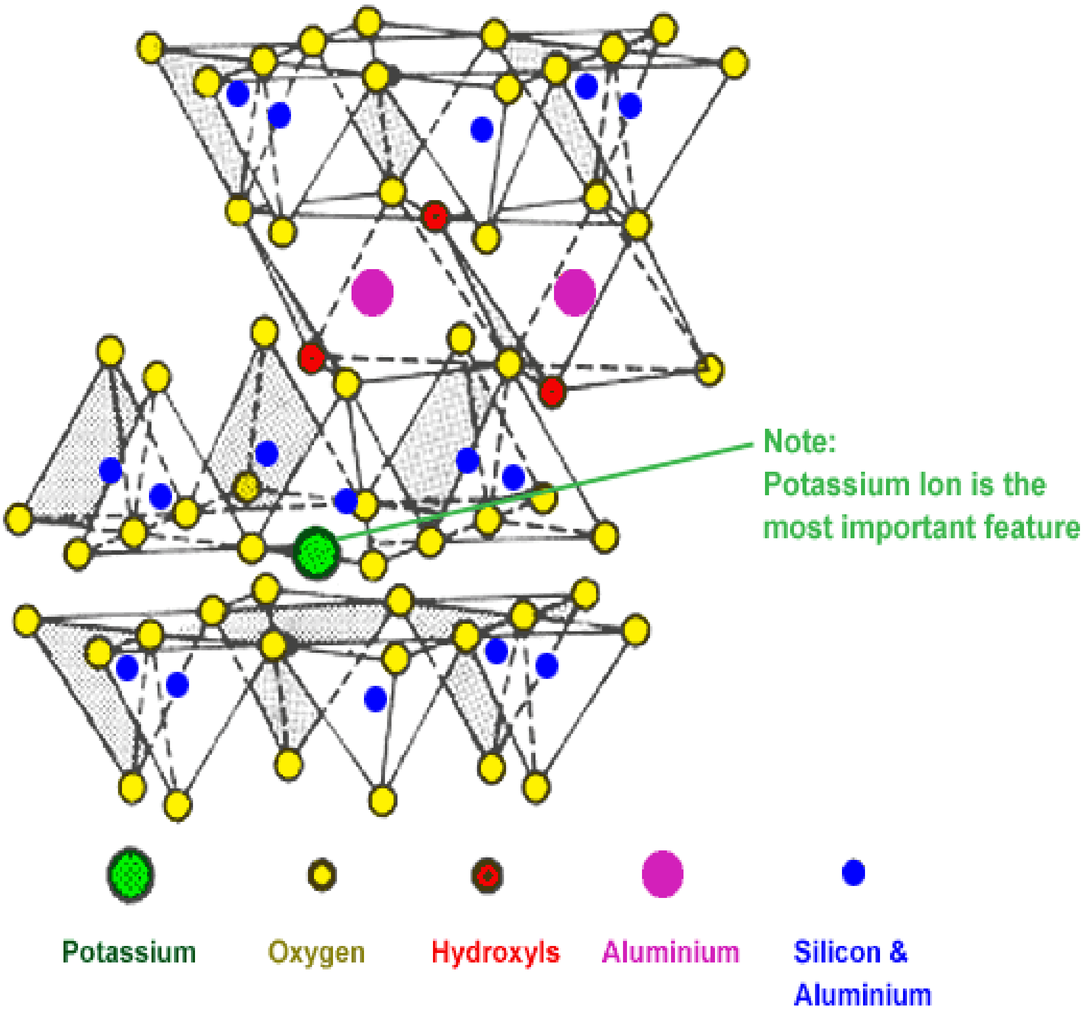

Figure 4 **Atomic structure of Illite**

2.4 Identification and classification of expansive soils

Some laboratory tests are available for the identification purposes of swelling soils. By differential thermal analysis, Microscopic examination, and X-ray diffraction. The presence of Montmorillonite in clay minerals allows the judgement of the expansiveness of the soil. This aspect is however very technical in nature. A simple aspect, as opposed to the aforementioned methods, is the free-swell test, that's done in the laboratory. This test is conducted by adding 10 gm of dry soil, passing through a 425 μ sieve into two separate 100 cc graduated jar – one filled with water, and the other with kerosene. Swelling occurs in the jar containing water. The swelled volume of the soil is then noted (after 24 hours period), and subsequently, the free swell index values, in percentage, are calculated. IS: 2720-II was followed for free swell index test.

$$\text{Free swell value } [I_n] \text{ (in \%age)} = \frac{(Final\ volume - initial\ volume)}{initial\ volume}\ x\ 100$$

Good grade, high swelling, commercial Bentonite has been reported to have free swell values varying from 1200% to 2000%. In general, the swelling potential of a soil is related to plasticity index. With corresponding range of plasticity index, various degrees of swelling capacities are as indicated through the following table:

Table 4 **Swelling potential vs. Plasticity Index**

Swelling potential	Plasticity Index
Low	0-15
Medium	15-24
High	24-46
Very High	>46

Several factors participate in deciding whether or not a soil with high swelling potential exhibit swelling characteristics. One of these factors, that occupy greatest importance, is the difference between soil moisture content at the time of construction, and final (equilibrium) moisture content finally achieved under various conditions allied with the complicated structure. The soil has a high swelling capacity if the equilibrium moisture content is higher than the soil moisture content. Large swelling pressure may develop as a result of the upheaving of the soil or structure, causing swelling.

2.5 Methods of recognizing expansive soils

Grouped into three categories, following are the methods of recognizing expansive soils:

- Mineralogical identification
- Indirect methods, such as soil suction, activity and index properties
- Direct measurement.

Impractical and uneconomical in practice, methods of mineralogical identification still hold importance in exploring basic properties of clay minerals. Direct measurement, out of the remaining two categories, offers the most useful data.

By their shattered or fissured condition, or obvious structural damage to existing buildings caused by such soils, potentially expansive soils are usually identified in the field. To classify expansive soil, potential swell, or potential expansion, or the degree of expansion is a favoured term used; from this, geotechnical engineers establish how good or bad the expansive soils are.

2.6 Causes of swelling

There are different theories, but the mechanism of swelling is still unclear. No conclusion to the mechanism have been reached. Soil consisting high percentage of clay or colloid, with Montmorillonite mineral present as the chief mineral is one of the most universally accepted reasons for the swelling of soils.

2.7 Swell Pressures

The pressure exerted by expansive soil when they swell, owing to their contact with water, is called swell pressure. The estimation of this swell pressure and likely becomes a very important task for designing a structure on such soils, or building the core of a dam, or constructing a road embankment, or taking a canal through such soils.

2.8 Factors affecting swelling

Initial moisture content, or the molding water in case of a re-molded sample is the most influencing factor. "The behaviour of re-molded clays is much as undisturbed clays", as per Holts' and Gibbs' findings. For a given dry density, the value of initial water content will be a key factor in determining the water affinity of a given sample, as well as its swell pressure. A minimum moisture content (w_n) required by a clay for swelling to begin beneath a pre-paved sub-grade is given by:

$$\boxed{w_n(\%) = 0.2w_1 + \mathrm{g}}$$

Where, w_1 = liquid limit

The factors that affect the swelling aspect of a soil largely depend on the soil's environmental conditions. With the intake of water, swelling is more in a soil element which is close to the surface, but if below the surface, the same soil exhibit negligible swelling because the overburden pressure neutralizes the developing swelling pressure of the dry soil.

Generally responsible for swelling are the following factors:

- ❖ Location of the soil sample from the ground surface
- ❖ Thickness, as well as shape of the sample
- ❖ Change in volume
- ❖ Temperature

- Nature of pore fluid
- Time
- Stress history
- Unit weight of the sample taken, etc.

2.9 Problems associated with the expansive soil

Generation of problems for all kinds of construction over expansive soils is common, leading us to believe that such types of soil are not suitable for these purposes. However, given the placement of these kinds of soil over the country, it leaves engineers no other choice but to develop different structures on the soil, well aware of the risk. These structures chiefly are a part of irrigation projects. Buildings, and other kinds of structures constructed over these soils are subjected to differential deflections. These deflections cause distressing, and in turn leads to damage of the structure.

Moreover, the reduction in moisture content due to the evaporation of water in soil causes shrinkage, and heaving of soil occurs when there is a disproportionate increase in moisture content. The level of ground water table also has a significant impact on the moisture content of these soils, which in return affect the shrinkage-swelling cycles. In seasons which are dry in nature, the surface of clayey soil shrinks, however, little evaporation is there on the clayey soil on which the building stands. This causes differential settlement at plinth level, posing danger to the structure.

If the construction of a building on such type of soil is done in its dry season, the base of the structure's foundation would experience swelling pressures when the partially saturated soil underneath starts imbibing water in the wet season, developing swelling pressures. When the pressure imposed by the structure on the foundation is less than the swelling pressure developed, upliftment of such a structure occurs, which would lead to formation of cracks. The imposed bearing pressure if the building is constructed in the wet season should be within the permissible limits of bearing pressure for the soil. A better practice is to construct a building during dry season, and completing it before the onset of wet seasons.

One of the methods of treatment of expansive soil to make them fit for the construction purposes is called stabilization. According to Petry (2002), assortment of stabilizers can be grouped into:

- By-product stabilizers (Quarry dust, Fly ash, Slag, Phosphor-gypsum, etc.)
- Traditional stabilizers (Cement, Lime, etc.)
- Non-traditional stabilizers (Sulfonated oils, Potassium compounds, Polymer, Enzymes, etc.)

Lots of geo-environmental problems are a result of industrial by-products whose disposal as fills in disposal sites adjacent to the industries demand large chunks of land, which can otherwise be utilized for construction, growing of vegetation, etc. purposes. Various attempts by different researchers and organizations have been made to utilize these by-products. Stabilization of expansive soil is one of the ways of fulfilling such a thing.

2.10 Stabilization using fly ash

Sharma *et al.* (1992), using mixtures of fly ash, blast furnace slag and gypsum, studied stabilization. He found that when fly ash, gypsum and blast furnace slag are used in proportions of 6:12:18, the swelling pressure decreases from 248 KN/m^2 to 17 KN/m^2, whereas an increase by 300% was observed in case of unconfined compressive strength.

Srivastava *et al.* (1997) studied the microscopic changes in the fabric and micro-structure of the expansive soil due to the addition of lime sludge and fly ash using SEM photography. He found that there were changes in the micro-structure and fabric of the expansive soil when 16% lime sludge and 16% fly ash were both added. Srivastava *et al.* (1999) have also stated that the best stabilizing effect of the swelling and consolidation behaviour in an expansive soil mixed with fly ash and lime sludge was obtained when 16% lime sludge and 16% fly ash were added.

Cokca (2001) found out that swelling pressure decreased by 75% after 7 day curing, and 79% after 28 day curing when soil specimens were treated with 25% Class C Fly ash (18.98% of CaO).

Pandian *et al.* (2001) made an effort towards stabilization of expansive soil by using Class F Fly ash. He found that fly ash can make for an effective additive when he saw that with 20% fly ash content, the CBR value of Black cotton soil improved (about 200%) significantly.

Turker *et al.* (2004) employed sand along with Class C & Class F fly ash for stabilization of expansive soil. Without any contradiction of belief, Class C fly ash was more effective in stabilization, and decrease in free swell with curing period was observed. The percentage content of soil, Class C fly ash and sand that gave the best result was 75%, 15% and 10% respectively.

Satyanarayana *et al.* (2004) aimed to study the mutual effect of addition of lime and fly ash on the engineering properties of the expansive soil. He found out that 70%, 26% and 4% were the optimum percent mixture of the ingredients for the construction of roads and embankments.

Phani Kumar *et al.* (2004) saw that the hydraulic conductivity, swelling properties and plasticity of expansive soil-fly ash mixture decreased, whereas the strength and dry unit weight increased with the increase of fly ash content in the mix. For a given water content, the resistance to penetration also increased with the increase in fly ash content.

Baytar (2005) contemplated the stabilization of expansive soils using desulphogypsum and fly ash acquired from a thermal power plant by 0 to 30%. A variable percentage of lime (0 to 8%) was appended into the expansive soil-desulphogypsum-fly ash mixture. The samples, thus formed, were cure for a period of 7 days and 28 days. It was observed that swelling percentage decrease, and there was an increase in rate of swell with increasing percentage of the stabilizer in the mixture. The curing process reduced the swelling percentage further; and with the addition of 30% desulphogypsum and 25% fly ash, reduction in swelling percentage were to such levels that stood comparable with the one where lime was only used as stabilizing compound for the expansive soil.

Amu *et al.* utilized fly ash and cement mixture for the stabilization purposes of expansive soil. Three distinct classes of samples: (i) 12% cement, (ii) 9% cement + 3% fly ash, and (iii) natural clay soil, were taken to be tested for Maximum Dry Densities (MDD), Unconfined Compressive Strength (UCS), Optimum Moisture Contents (OMC), California Bearing Ratios (CBR), and the Undrained Triaxial tests. The results of this test indicated that the sample with 9% cement and 3% fly ash showed better results with respect to CBR, OMC, MDD, and shearing resistance, in comparison to the other two samples. This indicated the value of fly ash as a stabilizing agent.

Sabat *et al.* (2005) studied the stabilization of expansive soil using fly ash-marble powder mixture. He concluded that the optimum proportions of soil, fly ash, and marble powder in the mixture in percentage by weight to give the best result were 65%, 20% and 15% respectively.

Rajesh *et al.* (2006) talked about experimental investigation of clay beds stabilized with fly ash-lime segments and fly ash segments. An observation of swelling in clay beds of 100 mm thickness strengthened with 30 mm diameter fly ash-lime and fly ash segments. There was a considerable decrease in heave in both fly ash-lime and fly ash columns. However, lime-fly ash mixture generated better results.

Wagh (2006) utilized rock flour, lime and fly ash independently, furthermore in diverse extent to stabilize the black cotton soil from Nagpur Plateau, India. Rock flour or fly ash, or both together, when added to the black cotton soil showed an improved value of CBR to some degree, and there was an increase in angle of shearing resistance with the reduction in cohesion value. CBR values increased significantly with the increase of both frictional resistance and cohesion where lime, in addition to both fly ash and rock flour, as added into the mixture.

Sharma *et al.* (2007) contemplated the impact on swelling of highly plastic expansive clay, and the compressibility of another non-expansive but highly plastic clay when fly ash was employed. At a given dry unit weight of the mixture, the swelling pressure and swell potential showed a decrease by nearly 50%. A decrease by 40% at 20% fly ash content in coefficient of secondary consolidation and compression index of both the samples was observed.

Buhler *et al.* (2007) considered the usage of lime and Class C fly ash in stabilization of expansive soils. He observed better results with lime than with Class C fly ash, when the reduction in linear shrinkage was better when the former was employed. This, however, established the characteristics of fly ash as a stabilizing material.

Chapter 3

MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Expansive soil

As a part of this investigation, the expansive black cotton soil was acquired from the site Khairi, Nagpur, Maharashtra. The black cotton soil thus obtained was carried to the laboratory in sacks. A small amount of soil was taken, sieved through 4.75 mm sieve, weighed, and air-dried before weighing again to determine the natural moisture content of the same. The various geotechnical properties of the procured soil are as follows:

Table 5 **Geotechnical properties of expansive soil**

Sl. No.	Properties	Code referred	Value
1	Specific Gravity	IS 2720 (Part 3/Sec 1) - 1980	2.44
2	Maximum Dry Density (MDD)	IS 2720 (Part 7) - 1980	1.52 gm/cc
3	Optimum Moisture Content (OMC)	IS 2720 (Part 7) - 1980	22.65%
4	Natural Moisture Content	IS 2720 (Part 2) - 1973	7.28%
5	Free Swell Index	IS 2720 (Part 40) - 1977	105%
6	Liquid Limit	IS 2720 (Part 5) - 1985	65%
7	Plastic Limit	IS 2720 (Part 5) - 1985	37.08%
8	Shrinkage Limit	IS 2720 (Part 6) -: 1972	17.37%

3.1.2 Fly ash

A waste material extracted from the gases emanating from coal fired furnaces, generally of a thermal power plant, is called fly ash. The mineral residue that is left behind after the burning of coal is the fly ash. The Electro Static Precipitator (ESP) of the power plants collect these fly ashes. Essentially consisting of alumina, silica and iron, fly ashes are micro-sized particles. Fly ash particles are generally spherical in size, and this property makes it easy for them to blend and flow, to make a suitable concoction. Both amorphous and crystalline nature of minerals are the content of fly ash generated. Its content varies with the change in nature of the coal used for the burning process, but it basically is a non-plastic silt. For the purpose of investigations in this study, fly ash was obtained from Sesa Sterlite, Jharsuguda, Odisha. To separate out the vegetation and foreign material, this fly ash was screen through a 2 mm sieve. The samples were dried in the oven for about 24 hours before further usage.

3.2 Methodology Adopted

To evaluate the effect of fly ash as a stabilizing additive in expansive soils, series of tests, where the content of fly ash in the expansive soil was varied in values of 10% to 50% (multiples of 10) by weight of the total quantity taken. The Indian Standard codes were followed during the conduction of the following experiments:

- Standard proctor test – IS : 2720 (Part 7) - 1980
- Unconfined compressive strength (UCS) test – IS : 2720 (Part 10) - 1991
- California bearing ratio (CBR) test – IS : 2720 (Part 16) - 1987
- Free swell index test – IS 2720 (Part 40) - 1977
- Liquid & Plastic limit test – IS 2720 (Part 5) - 1985

Chapter 4
RESULTS AND DISCUSSIONS

4.1 Standard proctor test for soil – fly ash mixture

Table 6 **Standard proctor test for expansive soil only**

Volume of Mold (m^3)	**Weight of soil in mold (kg)**	**Moist unit weight (g/cm^3)**	**Moisture content (%)**	**Dry unit weight (g/cm^3)**	**ZAV (g/cm^3)**
0.00099795	1.56	1.56	17.76	1.32	1.70
0.00099795	1.73	1.73	19.53	1.45	1.65
0.00099795	1.86	1.86	22.65	1.52	1.57
0.00099795	1.87	1.87	24.87	1.50	1.52
0.00099795	1.82	1.82	27.92	1.42	1.45

Table 7 **Standard proctor test for expansive soil + 10% fly ash mixture**

Volume of Mold (m^3)	**Weight of soil in mold (kg)**	**Moist unit weight (g/cm^3)**	**Moisture content (%)**	**Dry unit weight (g/cm^3)**	**ZAV (g/cm^3)**
0.00099795	1.60	1.60	15.18	1.39	1.78
0.00099795	1.76	1.76	19.09	1.48	1.66
0.00099795	1.83	1.83	22.13	1.50	1.58
0.00099795	1.80	1.81	27.96	1.41	1.45
0.00099795	1.77	1.77	32.71	1.33	1.35

Table 8 **Standard proctor test for expansive soil + 20% fly ash mixture**

Volume of Mold (m^3)	**Weight of soil in mold (kg)**	**Moist unit weight (g/cm^3)**	**Moisture content (%)**	**Dry unit weight (g/cm^3)**	**ZAV (g/cm^3)**
0.00099795	1.62	1.62	19.6	1.36	1.65
0.00099795	1.72	1.72	20.95	1.42	1.61
0.00099795	1.86	1.86	22.56	1.52	1.57
0.00099795	1.87	1.88	25.21	1.50	1.51
0.00099795	1.82	1.82	29.13	1.41	1.42

Table 9 **Standard proctor test for expansive soil + 30% fly ash mixture**

Volume of Mold (m^3)	**Weight of soil in mold (kg)**	**Moist unit weight (g/cm^3)**	**Moisture content (%)**	**Dry unit weight (g/cm^3)**	**ZAV (g/cm^3)**
0.00099795	1.64	1.64	15.12	1.43	1.78
0.00099795	1.76	1.76	18.96	1.48	1.67
0.00099795	1.86	1.86	21.27	1.53	1.60
0.00099795	1.87	1.88	24.71	1.50	1.52
0.00099795	1.82	1.82	28.13	1.42	1.44

Table 10 **Standard proctor test for expansive soil + 40% fly ash mixture**

Volume of Mold (m^3)	**Weight of soil in mold (kg)**	**Moist unit weight (g/cm^3)**	**Moisture content (%)**	**Dry unit weight (g/cm^3)**	**ZAV (g/cm^3)**
0.00099795	1.59	1.59	16.22	1.37	1.75
0.00099795	1.71	1.71	18.52	1.45	1.68
0.00099795	1.82	1.82	23.57	1.47	1.55
0.00099795	1.84	1.84	26.42	1.46	1.48
0.00099795	1.80	1.80	31.81	1.36	1.37

Table 11 **Standard proctor test for expansive soil + 50% fly ash mixture**

Volume of Mold (m^3)	**Weight of soil in mold (kg)**	**Moist unit weight (g/cm^3)**	**Moisture content (%)**	**Dry unit weight (g/cm^3)**	**ZAV (g/cm^3)**
0.00099795	1.53	1.53	14.11	1.34	1.81
0.00099795	1.61	1.61	17.23	1.37	1.71
0.00099795	1.73	1.73	21.34	1.42	1.60
0.00099795	1.78	1.78	25.76	1.42	1.50
0.00099795	1.76	1.76	31.2	1.34	1.38

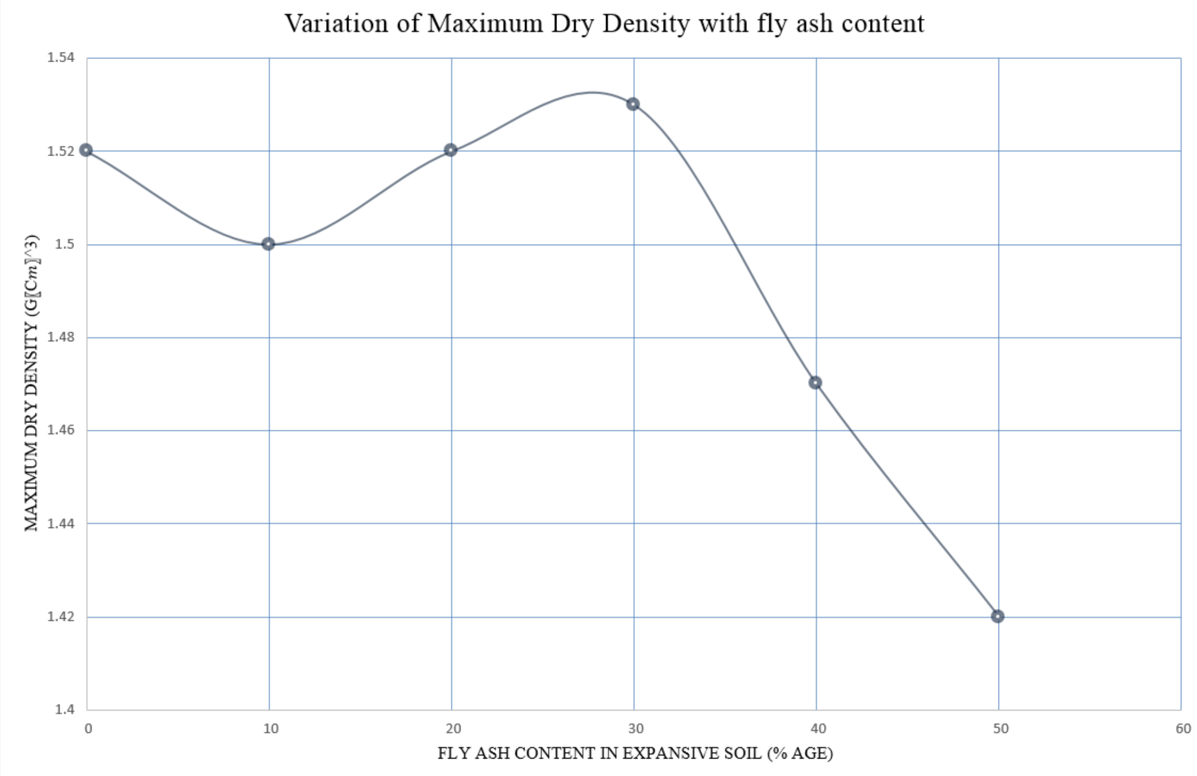

Figure 5 **Variation of MDD values with different fly ash content in expansive soil**

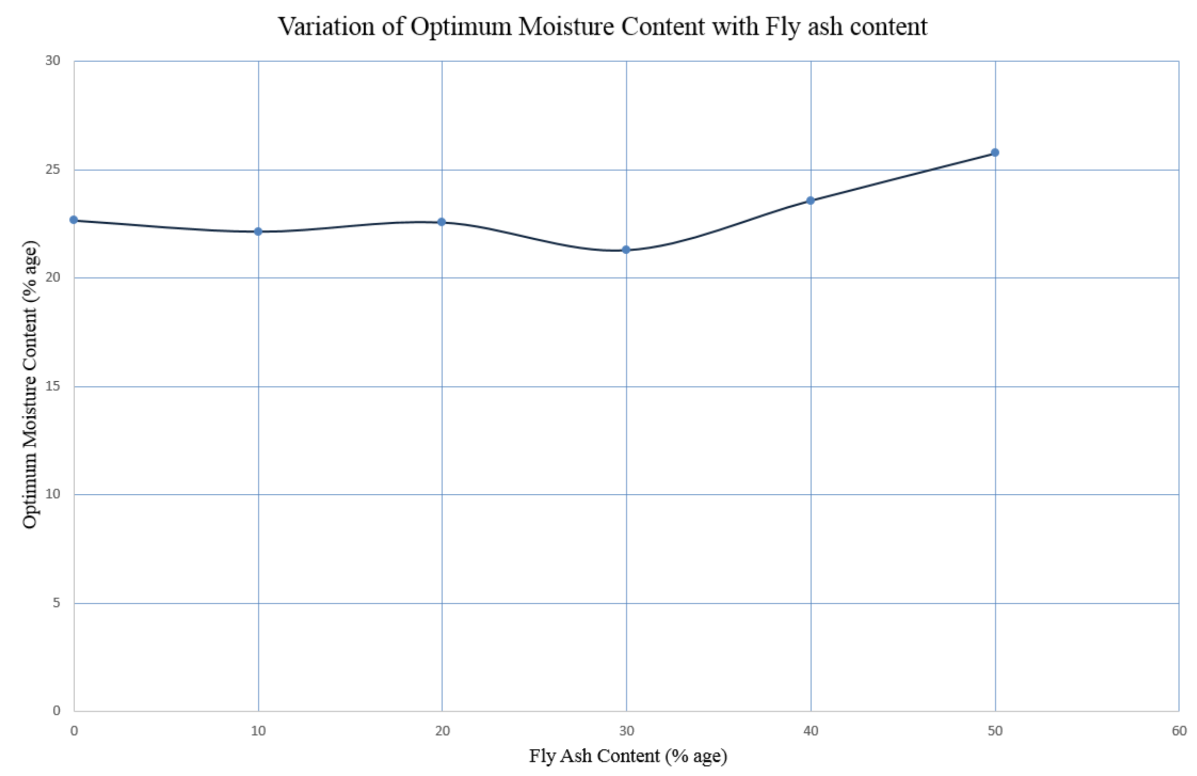

Figure 6 **Variation of OMC values with different fly ash content in expansive soil**

4.2 Unconfined Compressive Strength (UCS) test for soil – fly ash mixture

Table 12 **UCS test for expansive soil only**

Sl. No.	Dial gauge reading	Deformation (mm)	Proving ring reading	Load (kN)	Strain (%)	Corrected area (mm^2)	Compressive Strength (N/mm^2)
1	0	0	0	0	0	1133.54	0
2	50	0.5	14	0.019	0.6	1141.04	0.017
3	100	1	36	0.052	1.3	1148.65	0.044
4	150	1.5	69	0.098	1.9	1156.36	0.085
5	200	2	101	0.144	2.6	1164.17	0.123
6	250	2.5	111	0.158	3.3	1172.09	0.135
7	300	3	131	0.186	3.9	1180.12	0.158
8	350	3.5	149	0.212	4.6	1188.26	0.178
9	400	4	159	0.226	5.3	1196.51	0.189
10	450	4.5	166	0.236	5.9	1204.88	0.196
11	500	5	168	0.240	6.6	1213.36	0.197
12	550	5.5	169	0.241	7.2	1221.97	0.197
13	600	6	169	0.241	7.9	1230.70	0.196
14	650	6.5	168	0.240	8.5	1239.55	0.193
15	700	7	168	0.240	9.2	1248.53	0.191
16	750	7.5	167	0.238	9.8	1257.65	0.189
17	800	8	165	0.235	10.5	1266.89	0.185
18	850	8.5	165	0.235	11.2	1276.28	0.184
19	900	9	163	0.232	11.8	1285.80	0.180
20	950	9.5	162	0.231	12.5	1295.47	0.178

Table 13 **UCS test for expansive soil + 10% fly ash**

Sl. No.	**Dial gauge reading**	**Deformation (mm)**	**Proving ring reading**	**Load (kN)**	**Strain (%)**	**Corrected area (mm^2)**	**Compressive Strength (N/mm^2)**
1	0	0	0	0	0	1133.54	0
2	50	0.5	10	0.014	0.6	1141.04	0.012
3	100	1	24	0.034	1.3	1148.65	0.029
4	150	1.5	49	0.069	1.9	1156.36	0.060
5	200	2	67	0.095	2.6	1164.17	0.082
6	250	2.5	90	0.128	3.3	1172.09	0.109
7	300	3	101	0.144	3.9	1180.12	0.122
8	350	3.5	119	0.169	4.6	1188.26	0.142
9	400	4	126	0.179	5.3	1196.51	0.150
10	450	4.5	137	0.195	5.9	1204.88	0.162
11	500	5	144	0.205	6.6	1213.36	0.169
12	550	5.5	146	0.208	7.2	1221.97	0.170
13	600	6	169	0.241	7.9	1230.70	0.195
14	650	6.5	168	0.239	8.5	1239.55	0.193
15	700	7	168	0.239	9.2	1248.53	0.191
16	750	7.5	167	0.238	9.8	1257.65	0.189
17	800	8	165	0.235	10.5	1266.89	0.185
18	850	8.5	165	0.235	11.2	1276.28	0.184

Table 14 **UCS test for expansive soil + 20% fly ash**

Sl. No.	**Dial gauge reading**	**Deformation (mm)**	**Proving ring reading**	**Load (kN)**	**Strain (%)**	**Corrected area (mm^2)**	**Compressive Strength (N/mm^2)**
1	0	0	0	0	0	1133.54	0
2	50	0.5	11	0.015	0.6	1141.04	0.013
3	100	1	35	0.049	1.3	1148.65	0.043
4	150	1.5	71	0.101	1.9	1156.36	0.087
5	200	2	98	0.139	2.6	1164.17	0.119
6	250	2.5	109	0.155	3.3	1172.09	0.132
7	300	3	132	0.188	3.9	1180.12	0.159
8	350	3.5	153	0.218	4.6	1188.26	0.183
9	400	4	164	0.233	5.3	1196.51	0.195
10	450	4.5	170	0.242	5.9	1204.88	0.201
11	500	5	173	0.246	6.6	1213.36	0.203
12	550	5.5	177	0.252	7.2	1221.97	0.206
13	600	6	177	0.252	7.9	1230.70	0.204
14	650	6.5	178	0.253	8.5	1239.55	0.204
15	700	7	176	0.250	9.2	1248.53	0.201
16	750	7.5	175	0.249	9.8	1257.65	0.198
17	800	8	175	0.249	10.5	1266.89	0.196
18	850	8.5	174	0.248	11.2	1276.28	0.194
19	900	9	173	0.246	11.8	1285.80	0.191

Table 15 **UCS test for expansive soil + 30% fly ash mixture**

Sl. No.	**Dial gauge reading**	**Deformation (mm)**	**Proving ring reading**	**Load (kN)**	**Strain (%)**	**Corrected area (mm^2)**	**Compressive Strength (N/mm^2)**
1	0	0	0	0	0	1133.54	0
2	50	0.5	6	0.008	0.6	1141.05	0.007
3	100	1	24	0.034	1.3	1148.65	0.029
4	150	1.5	48	0.068	1.9	1156.36	0.059
5	200	2	71	0.101	2.6	1164.17	0.086
6	250	2.5	93	0.132	3.3	1172.09	0.113
7	300	3	107	0.152	3.9	1180.12	0.129
8	350	3.5	128	0.182	4.6	1188.26	0.153
9	400	4	141	0.201	5.3	1196.51	0.168
10	450	4.5	147	0.209	5.9	1204.88	0.174
11	500	5	150	0.213	6.6	1213.36	0.176
12	550	5.5	151	0.215	7.2	1221.97	0.176
13	600	6	151	0.215	7.9	1230.70	0.175
14	650	6.5	150	0.213	8.5	1239.55	0.172
15	700	7	149	0.212	9.2	1248.53	0.170
16	750	7.5	148	0.211	9.8	1257.65	0.167

Table 16 **UCS test for expansive soil + 40% fly ash mixture**

Sl. No.	**Dial gauge reading**	**Deformation (mm)**	**Proving ring reading**	**Load (kN)**	**Strain (%)**	**Corrected area (mm^2)**	**Compressive Strength (N/mm^2)**
1	0	0	0	0	0	1133.54	0
2	50	0.5	8	0.011	0.6	1141.05	0.01
3	100	1	21	0.030	1.3	1148.65	0.026
4	150	1.5	46	0.065	1.9	1156.36	0.057
5	200	2	71	0.101	2.6	1164.17	0.087
6	250	2.5	92	0.131	3.3	1172.09	0.111
7	300	3	114	0.162	3.9	1180.12	0.137
8	350	3.5	132	0.188	4.6	1188.26	0.158
9	400	4	140	0.199	5.3	1196.51	0.166
10	450	4.5	144	0.205	5.9	1204.88	0.170
11	500	5	145	0.206	6.6	1213.36	0.170
12	550	5.5	145	0.206	7.2	1221.97	0.169
13	600	6	145	0.206	7.9	1230.70	0.168
14	650	6.5	144	0.205	8.5	1239.55	0.165
15	700	7	143	0.203	9.2	1248.53	0.163

Table 17 **UCS test for expansive soil + 50% fly ash mixture**

Sl. No.	**Dial gauge reading**	**Deformation (mm)**	**Proving ring reading**	**Load (kN)**	**Strain (%)**	**Corrected area (mm^2)**	**Compressive Strength (N/mm^2)**
1	0	0	0	0	0	1133.54	0
2	50	0.5	12	0.017	0.6	1141.05	0.015
3	100	1	36	0.051	1.3	1148.65	0.044
4	150	1.5	69	0.098	1.9	1156.36	0.085
5	200	2	92	0.1311	2.6	1164.17	0.112
6	250	2.5	104	0.148	3.3	1172.09	0.126
7	300	3	124	0.176	3.9	1180.12	0.149
8	350	3.5	130	0.185	4.6	1188.26	0.156
9	400	4	139	0.198	5.2	1196.51	0.165
10	450	4.5	141	0.201	5.9	1204.88	0.166
11	500	5	142	0.202	6.5	1213.36	0.166
12	550	5.5	142	0.202	7.2	1221.97	0.165
13	600	6	140	0.199	7.9	1230.70	0.162
14	650	6.5	140	0.199	8.5	1239.55	0.16
15	700	7	139	0.198	9.2	1248.53	0.158
16	750	7.5	138	0.196	9.8	1257.65	0.156

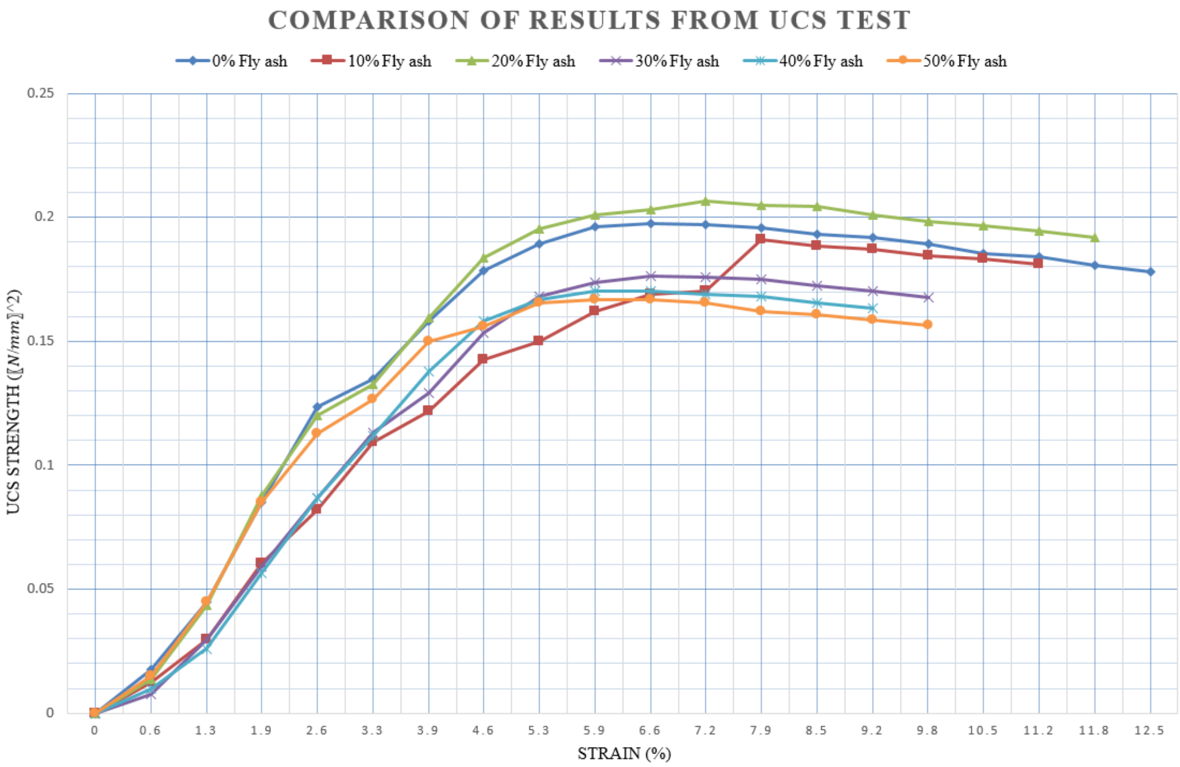

Figure 7 **Comparison of UCS test readings in expansive soil, with varying fly ash content**

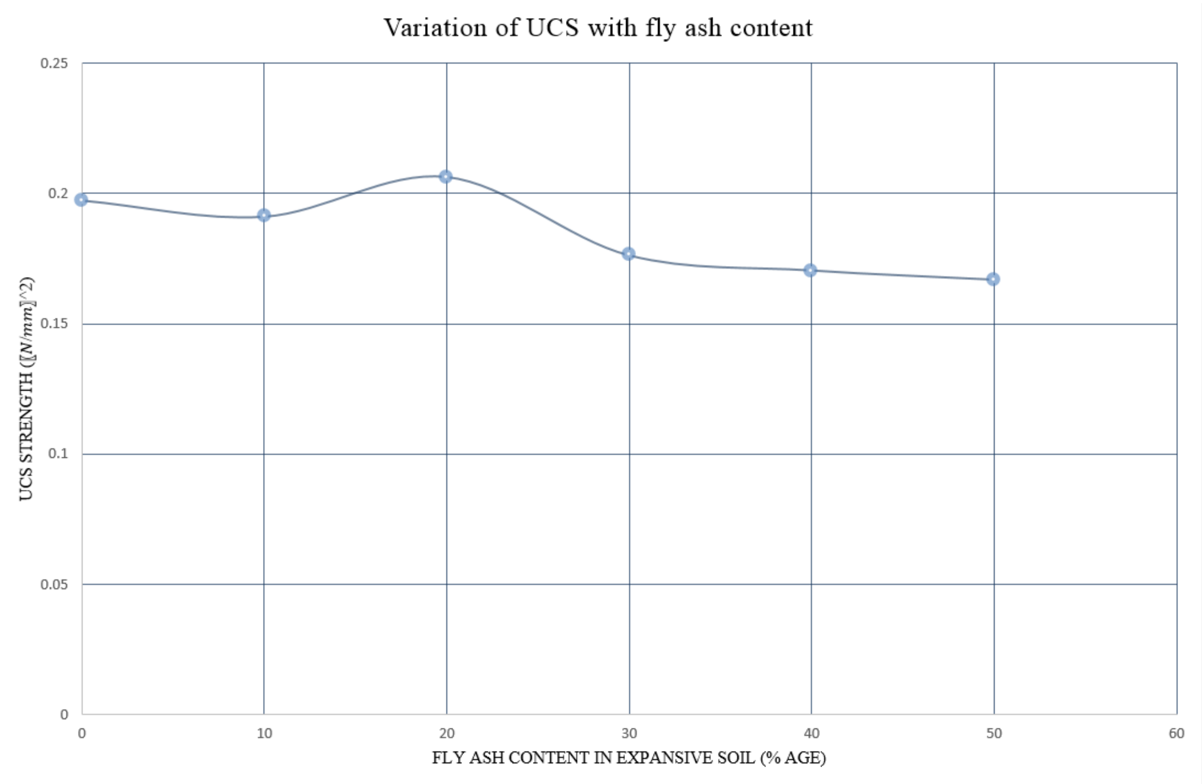

Figure 8 **Variation of UCS values of expansive soil with different fly ash content**

4.3 Un-soaked California Bearing Ratio (CBR) test for soil – fly ash mixture

Table 1 **Un-soaked CBR test for expansive soil only**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	1	2.47	0.12		
2	0.5	6	14.82	0.75		
3	1	17	42.01	2.14		
4	1.5	24	59.30	3.02		
5	2	28	69.19	3.52		
6	2.5	32	79.07	4.03	70	5.75
7	3	36	88.95	4.53		
8	3.5	40	98.84	5.03		
9	4	44	108.72	5.54		
10	4.5	47	116.14	5.91		
11	5	50	123.55	6.29	105	5.99
12	5.5	52	128.49	6.54		
13	6	53	130.96	6.67		
14	6.5	54	133.43	6.79		
15	7	55	135.90	6.92		
16	7.5	57	140.84	7.17	134	5.35
17	8	58	143.32	7.30		
18	8.5	58	143.32	7.30		

Table 19 **Un-soaked CBR test for expansive soil + 10% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	4	9.88	0.49		
2	0.5	10	24.71	1.23		
3	1	28	69.19	3.45		
4	1.5	44	108.72	5.43		
5	2	52	128.49	6.42		
6	2.5	59	145.79	7.28	70	10.40
7	3	66	163.08	8.14		
8	3.5	72	177.91	8.88		
9	4	78	192.74	9.63		
10	4.5	83	205.09	10.24		
11	5	90	222.39	11.11	105	10.58
12	5.5	95	234.74	11.72		
13	6	98	242.16	12.09		
14	6.5	100	247.10	12.34		
15	7	101	249.57	12.46		
16	7.5	102	252.04	12.59	134	9.39
17	8	102	252.04	12.59		

Table 20 **Un-soaked CBR test for expansive soil + 20% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	8	19.77	1.01		
2	0.5	25	61.77	3.15		
3	1	42	103.78	5.29		
4	1.5	60	148.26	7.55		
5	2	73	180.38	9.19		
6	2.5	83	205.09	10.45	70	14.93
7	3	96	237.21	12.08		
8	3.5	110	271.81	13.85		
9	4	122	301.46	15.36		
10	4.5	133	328.64	16.74		
11	5	139	343.47	17.50	105	16.67
12	5.5	146	360.76	18.38		
13	6	153	378.06	19.26		
14	6.5	157	387.94	19.76		
15	7	159	392.89	20.02		
16	7.5	161	397.83	20.27		
17	8	163	402.77	20.52	134	15.31
18	8.5	164	405.24	20.65		
19	9	165	407.71	20.77		
20	9.5	165	407.71	20.77		

Table 21 **Un-soaked CBR test for expansive soil + 30% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	3	7.41	0.37		
2	0.5	9	22.24	1.13		
3	1	19	46.95	2.39		
4	1.5	29	71.66	3.65		
5	2	37	91.42	4.66		
6	2.5	52	128.49	6.54	70	9.35
7	3	57	140.84	7.17		
8	3.5	65	160.61	8.18		
9	4	71	175.44	8.94		
10	4.5	77	190.26	9.69		
11	5	83	205.09	10.45	105	9.95
12	5.5	86	212.50	10.82		
13	6	89	219.92	11.20		
14	6.5	91	224.86	11.45		
15	7	92	227.33	11.58		
16	7.5	93	229.80	11.71	134	8.73
17	8	94	232.27	11.83		
18	8.5	94	232.27	11.83		

Table 22 **Un-soaked CBR test for expansive soil + 40% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	2	4.94	0.25		
2	0.5	7	17.30	0.88		
3	1	17	42.01	2.13		
4	1.5	28	69.19	3.51		
5	2	38	93.90	4.77		
6	2.5	46	113.67	5.77	70	8.25
7	3	52	128.49	6.53		
8	3.5	58	143.32	7.28		
9	4	63	155.67	7.91		
10	4.5	68	168.03	8.53		
11	5	72	177.91	9.04	105	8.61
12	5.5	76	187.80	9.54		
13	6	80	197.68	10.04		
14	6.5	83	205.09	10.42		
15	7	86	212.51	10.79		
16	7.5	89	219.92	11.17	134	8.34
17	8	91	224.86	11.42		
18	8.5	93	229.80	11.67		
19	9	94	232.27	11.80		
20	9.5	94	232.27	11.80		
21	10	94	232.27	11.80	162	7.28

Table 23 **Un-soaked CBR test for expansive soil + 50% fly ash mixture**

Sl. No.	Plunger penetration (mm)	Dial gauge readings	Applied load (kg)	CBR stress (kg/cm^2)	Standard load intensity (kg/cm^2)	CBR intensity (% age)
1	0	2	4.94	0.25		
2	0.5	5	12.36	0.63		
3	1	14	34.59	1.76		
4	1.5	23	56.83	2.90		
5	2	33	81.54	4.16		
6	2.5	41	101.31	5.16	70	7.37
7	3	48	118.61	6.04		
8	3.5	55	135.91	6.93		
9	4	61	150.73	7.68		
10	4.5	66	163.09	8.31		
11	5	71	175.44	8.94	105	8.51
12	5.5	75	185.33	9.44		
13	6	79	195.21	9.95		
14	6.5	82	202.62	10.32		
15	7	86	212.51	10.83		
16	7.5	89	219.92	11.21	134	8.36
17	8	90	222.39	11.33		
18	8.5	91	224.86	11.46		
19	9	91	224.86	11.46		

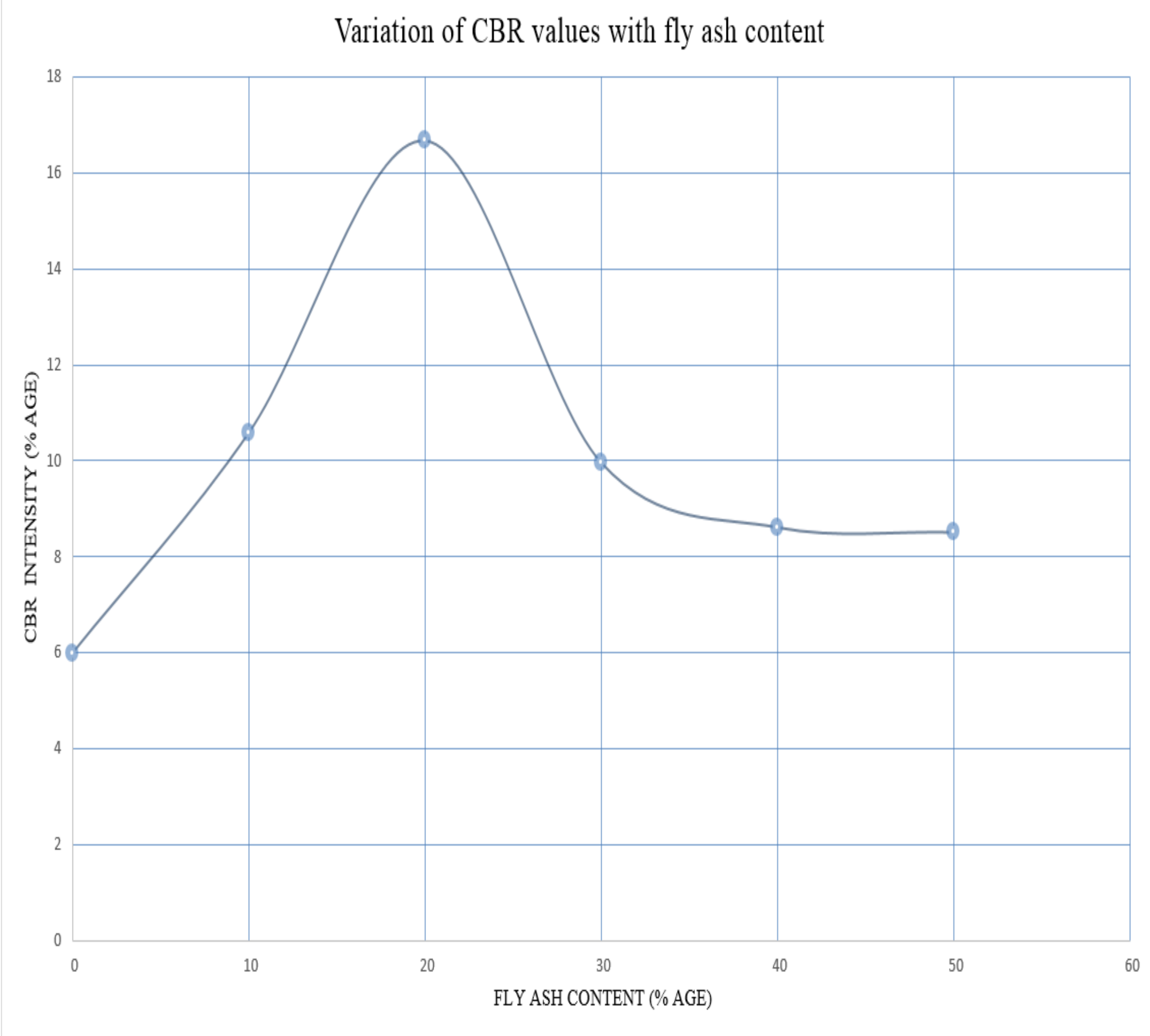

Figure 9 **Variation of Un-soaked CBR values of expansive soil with varying fly ash content**

4.4 Soaked California Bearing Ratio (CBR) test for soil – fly ash mixture

Table 24 **Soaked CBR test for expansive soil**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	0	0.00	0.00		
2	0.5	3	7.41	0.38		
3	1	9	22.24	1.13		
4	1.5	15	37.07	1.89		
5	2	20	49.42	2.52		
6	2.5	23	56.83	2.90	70	4.14
7	3	26	64.25	3.27		
8	3.5	30	74.13	3.78		
9	4	33	81.54	4.16		
10	4.5	35	86.49	4.41		
11	5	37	91.43	4.66	105	4.44
12	5.5	38	93.90	4.78		
13	6	39	96.37	4.91		
14	6.5	39	96.37	4.91		
15	7	40	98.84	5.04		
16	7.5	40	98.84	5.04	134	3.76
17	8	40	98.84	5.04		

Table 25 **Soaked CBR test for expansive soil + 10% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	2.47	0.13			2.47
2	0.5	9.88	0.50			9.88
3	1	19.77	1.01			19.77
4	1.5	29.65	1.51			29.65
5	2	39.54	2.01			39.54
6	2.5	51.89	2.64	70	3.78	51.89
7	3	61.78	3.15			61.78
8	3.5	71.66	3.65			71.66
9	4	79.07	4.03			79.07
10	4.5	84.01	4.28			84.01
11	5	88.96	4.53	105	4.32	88.96
12	5.5	91.43	4.66			91.43
13	6	93.90	4.78			93.90
14	6.5	96.37	4.91			96.37
15	7	96.37	4.91			96.37
16	7.5	96.37	4.91	134	3.66	96.37

Table 26 **Soaked CBR test for expansive soil + 20% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	1	2.47	0.13		
2	0.5	8	19.77	1.01		
3	1	16	39.54	2.01		
4	1.5	21	51.89	2.64		
5	2	25	61.78	3.15		
6	2.5	29	71.66	3.65	70	5.22
7	3	33	81.54	4.16		
8	3.5	37	91.43	4.66		
9	4	40	98.84	5.04		
10	4.5	42	103.78	5.29		
11	5	44	108.72	5.54	105	5.28
12	5.5	46	113.67	5.79		
13	6	47	116.14	5.92		
14	6.5	48	118.61	6.04		
15	7	49	121.08	6.17		
16	7.5	50	123.55	6.30	134	4.70
17	8	51	126.02	6.42		
18	8.5	51	126.02	6.42		

Table 27 **Soaked CBR test for expansive soil + 30% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	1	2.47	0.13		
2	0.5	6	14.83	0.76		
3	1	13	32.12	1.64		
4	1.5	20	49.42	2.52		
5	2	26	64.25	3.27		
6	2.5	30	74.13	3.78	70	5.40
7	3	36	88.96	4.53		
8	3.5	40	98.84	5.04		
9	4	42	103.78	5.29		
10	4.5	45	111.20	5.67		
11	5	46	113.67	5.79	105	5.52
12	5.5	48	118.61	6.04		
13	6	50	123.55	6.30		
14	6.5	51	126.02	6.42		
15	7	52	128.49	6.55		
16	7.5	53	130.96	6.67	132	5.06
17	8	54	133.43	6.80		
18	8.5	54	133.43	6.80		

Table 28 **Soaked CBR test for expansive soil + 40% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	1	2.47	0.13		
2	0.5	3	7.41	0.38		
3	1	6	14.83	0.76		
4	1.5	10	24.71	1.26		
5	2	15	37.07	1.89		
6	2.5	20	49.42	2.52	70	3.60
7	3	24	59.30	3.02		
8	3.5	28	69.19	3.53		
9	4	30	74.13	3.78		
10	4.5	32	79.07	4.03		
11	5	34	84.01	4.28	105	4.08
12	5.5	35	86.49	4.41		
13	6	36	88.96	4.53		
14	6.5	38	93.90	4.78		
15	7	39	96.37	4.91		
16	7.5	39	96.37	4.91	134	3.66

Table 29 **Soaked CBR test for expansive soil + 50% fly ash mixture**

Sl. No.	**Plunger penetration (mm)**	**Dial gauge readings**	**Applied load (kg)**	**CBR stress (kg/cm^2)**	**Standard load intensity (kg/cm^2)**	**CBR intensity (% age)**
1	0	0	0.00	0.00		
2	0.5	2	4.94	0.25		
3	1	6	14.83	0.76		
4	1.5	11	27.18	1.39		
5	2	15	37.07	1.89		
6	2.5	18	44.48	2.27	70	3.24
7	3	21	51.89	2.64		
8	3.5	24	59.30	3.02		
9	4	26	64.25	3.27		
10	4.5	28	69.19	3.53		
11	5	29	71.66	3.65	105	3.48
12	5.5	30	74.13	3.78		
13	6	32	79.07	4.03		
14	6.5	33	81.54	4.16		
15	7	34	84.01	4.28		
16	7.5	35	86.49	4.41	134	3.29
17	8	36	88.96	4.53		
18	8.5	37	91.43	4.66		
19	9	37	91.43	4.66		

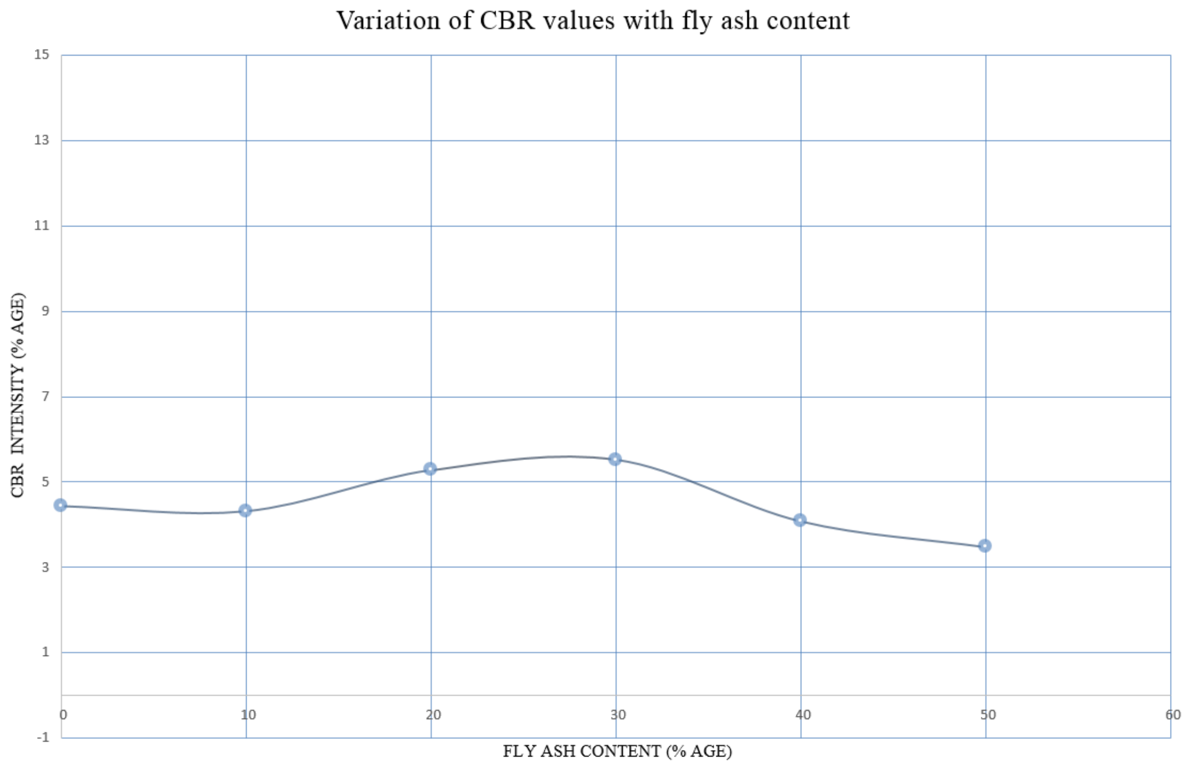

Figure 10 **Variation of soaked CBR values of expansive soil with varying fly ash content**

4.5 Changes in plasticity index and free swell ratio for soil – fly ash mixture

Table 30 **Variation of plasticity index and free swell ratio with fly ash content in expansive soil**

Mixture	Liquid limit	Plastic limit	Plasticity index	Free swell ratio
Only soil	65.6	35.8	29.8	2.05
Soil + 10% fly ash	61.2	34.6	26.6	1.92
Soil + 20% fly ash	58.8	33.2	25.6	1.84
Soil + 30% fly ash	56.4	31.5	24.9	1.77
Soil + 40% fly ash	51.8	28.67	23.13	1.63
Soil + 50% fly ash	49.2	26.3	22.9	1.53

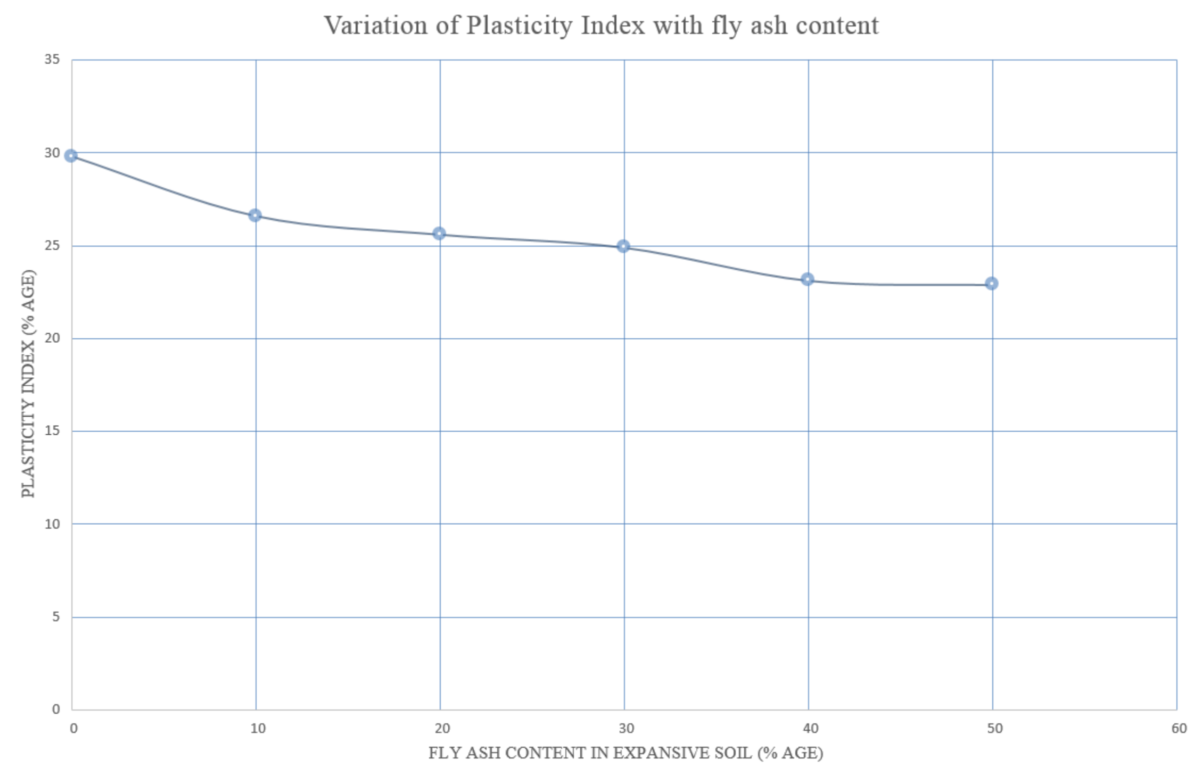

Figure 11 **Variation of plasticity index values of expansive soil with varying fly ash content**

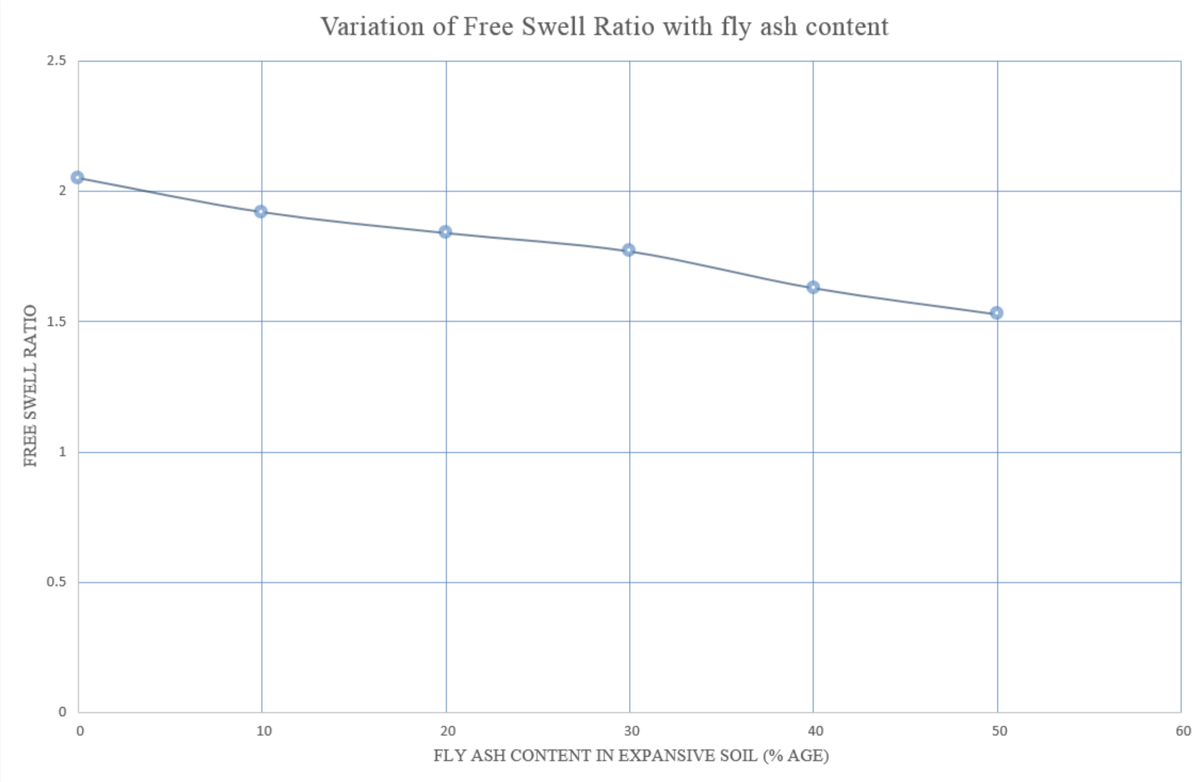

Figure 12 **Variation of free swell ratio values of expansive soil with varying fly ash content**

4.8 Discussions

- Black cotton soil is combined with altering percentage of fly ash (from 0% to 50%, intervals in multiples of 10) by weight to observe its effect as an additive on the expansive soil.
- Maximum Dry Density (MDD) was found to change with varying content of fly. The highest value observed being at fly ash content of 30% by weight.
- The change in Unconfined Compressive Strength (UCS) of the soil with varying content of fly ash is observed. The graph shows the variation of UCS with changing fly ash content. The maximum value of UCS was obtained with the mixture of soil and 20% fly ash content by weight.
- Both un-soaked and soaked California Bearing Ratio (CBR) tests are conducted with varying content of fly ash in the black cotton soil. From the graphical comparison of these values against the varying fly ash content, it can be observed that 20% fly ash and 30% fly ash content gave the maximum value of CBR intensity in un-soaked and soaked soil-fly ash mixture respectively.
- The liquid limit and plastic limit of the soil-fly ash mixture varied with the changing fly ash content. Plasticity index values were computed from these experiments, which showed a consistent decreasing pattern with the increase of fly ash content.
- From the free swell ratio tests on the soil-fly ash mixture, the value of free swell ratio decreased with the increasing fly ash content.

Chapter 5
CONCLUSION

5.1 Conclusions

Based on the results obtained and comparisons made in the present study, the following conclusions can be drawn:

- The Maximum Dry Density (MDD) value of the black cotton soil initially decreased with the addition of fly ash. Then, it showed increment with increasing fly ash content in the soil-fly ash mixture. The maximum value of MDD was observed for a mixture of soil and 30% of fly ash content by weight. The MDD values consistently decreased thereafter.
- The Unconfined Compressive Strength (UCS) of the soil with variation of fly ash content showed similar trend as that of the MDD values, except the fact that the peak value was observed for a fly ash content of 20% by weight.
- In un-soaked California Bearing Ratio (CBR) tests of soil conducted with varying fly ash content, the CBR increased gradually with the increase in fly ash content till its valuation was 20% by weight of the total mixture; it decreased thereafter.
- The change in case of soaked California Bearing Ratio (CBR) tests of soil with varying fly ash content was, however, uneven. It decreased with the initial addition of fly ash (10% by weight of total mixture), and then increased till fly ash content reached 30% by weight of total mixture. The values decreased thereafter.
- With the increasing fly ash content in the soil-fly ash mixture, the decrease in value of free swell ratio was remarked. This decrease was also reciprocated by the plasticity index values. Plasticity index values are directly proportional to percent swell in an expansive soil, thus affecting the swelling behavior of the soil-fly ash mixture.
- Thus, fly ash as an additive decreases the swelling, and increases the strength of the black cotton soil.

5.2 Scope for future study

- Fly ash along with another additive like lime, murrum, cement, and other such materials can be used together, and may be varied in quantity to obtain the best possible stabilizing mixture.

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